IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:)
GOLDSTEIN)
) Examiner: H. Le
Serial No. **10/060,497**)
)
Filing Date: **JANUARY 30, 2002**) Art Unit: 2821
)
For: **PHASED ARRAY ANTENNA INCLUDING ARCHIMEDEAN SPIRAL ELEMENT ARRAY AND RELATED METHODS**)

DECLARATION UNDER 37 CFR 1.131

MS Non-Fee Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

I, M. Lawrence Goldstein, hereby declare that:

1. I am the sole inventor for the above-identified patent application.

2. Prior to July 11, 2001, I conceived and reduced to practice the invention as described and claimed in the subject patent application, as evidenced by the following documents:

(a) a printout of a MathCAD analysis for an Archimedean spiral lattice that I personally prepared prior to July 11, 2001, which is attached hereto as Appendix A (note the definition of the Archimedean spiral lattice on page 1, and graph

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and simulation results thereof provided on page 4); and

(b) a printout of a power point presentation also personally prepared by myself prior to July 11, 2001, which is attached hereto as Appendix B, demonstrating MathCAD simulation results for various test configurations of my Archimedean spiral lattice (see pages 1-3 and 9), and also providing Mathcad simulation results for various prior art arrays (namely an aperiodic concentric ring lattice on page 4, and various periodic triangular lattices on pages 5-8) for comparison purposes.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

2/16/03
Date

M. Lawrence Goldstein

The Element

$$\mathrm{cosgain}(\theta, n) := 10\cdot\log\left[\frac{2\cdot(|\cos(\theta)|)^n}{\int_0^{\pi\cdot 0.5} (|\cos(\theta)|)^n\cdot\sin(\theta)\,d\theta}\right]$$ cos^n pattern

$\mathrm{ElementGain}(\theta) := \mathrm{cosgain}(\theta, 2.155)$ $\quad \mathrm{ElementGain}(0\cdot deg) = 8$ Element gain vs. scan

$c := 2.997925\cdot 10^8\cdot\frac{m}{sec}$ $\quad \lambda := \frac{c}{f}$ $\quad k_o := 2\cdot\frac{\pi}{\lambda}$ frequency

$G_{array} := 10\cdot\log(N) + \mathrm{ElementGain}(0\cdot deg)$ maximum possible array gain (boresight)

The Array

$$\mathrm{Next}(\theta 1) := \left|\begin{array}{l} \Delta\theta \leftarrow 10\cdot deg \\ \theta 2 \leftarrow \theta 1 + \Delta\theta \\ \text{for } i \in 1..5 \\ \quad \left|\begin{array}{l} \theta 2 \leftarrow \theta 2 - \Delta\theta \\ \Delta\theta \leftarrow \frac{\Delta\theta}{10} \\ \text{while } 4\cdot\pi^2 \ge \theta 1^2 + \theta 2^2 - 2\cdot\theta 1\cdot\theta 2\cdot\cos(\theta 1 - \theta 2) \\ \quad \theta 2 \leftarrow \theta 2 + \Delta\theta \end{array}\right. \\ \theta 2 \end{array}\right.$$ angles for spiral lattice

The Subarray

$s := 10^{\frac{\mathrm{ElementGain}(0\cdot deg)}{20}}\cdot\frac{\lambda}{\pi}$ $\quad s = 1.123\,in$ required min spacing

$\theta_{s_1} := 0\cdot deg$ $\quad i := 2..N$ $\quad \theta_{s_i} := \mathrm{Next}\left(\theta_{s_{i-1}}\right)$ $\quad i := 1..N$ $\quad d_{i,1} := \theta_{s_i}\cdot\cos\left(\theta_{s_i}\right)\cdot\frac{s}{2\pi}$ $\quad d_{i,2} := \theta_{s_i}\cdot\sin\left(\theta_{s_i}\right)\cdot\frac{s}{2\pi}$ array lattice

$k := 1..N$ $\quad \Delta d_{i,k} := \mathrm{if}\left[i = k, 1000\cdot in, \sqrt{\left(d_{i,1} - d_{k,1}\right)^2 + \left(d_{i,2} - d_{k,2}\right)^2}\right]$ $\mathrm{min}(\Delta d) = 1.119\,in$ min spacing

$D := \max\left(\overrightarrow{\sqrt{\left(d^{\langle 1\rangle}\right)^2 + \left(d^{\langle 2\rangle}\right)^2}}\right)\cdot 2 + s$ $\quad \eta := N\cdot\left(\frac{s}{D}\right)^2$ aperture efficiency

Beamforming

$$PQ(\alpha) := \mathrm{round}\left(\frac{\alpha \cdot 2^{nbits}}{2 \cdot \pi}\right) \cdot \frac{2 \cdot \pi}{2^{nbits}}$$

phase quantization for an n-bit phase shifter

$$Err(x) := x \cdot \left[10^{\frac{rnd(MagErr) - 0.5 \cdot MagErr}{20}} \cdot e^{j \cdot [(rnd(PhaseErr) - 0.5 \cdot PhaseErr) \cdot deg]} \right]$$

random mag & phase errors

$$w_i := Err\left[e^{j \cdot PQ\left[k_o \cdot \sin(\theta_o) \cdot \left[\left(d^{\langle 1 \rangle}\right)_i \cdot \cos(\phi_o) + \left(d^{\langle 2 \rangle}\right)_i \cdot \sin(\phi_o) \right] \right]} \right] \qquad Pt := \sum_i \left(\left| w_i \right| \right)^2$$

array element weights

$$AG(\theta, \phi) := 10 \cdot \log\left[\frac{\left[\left| \sum_i w_i \cdot e^{-j \cdot k_o \cdot \sin(\theta) \cdot \left[\left(d^{\langle 1 \rangle}\right)_i \cdot \cos(\phi) + \left(d^{\langle 2 \rangle}\right)_i \cdot \sin(\phi) \right]} \right| \right]^2}{Pt} \right] + ElementGain(\theta)$$

array gain

$$\Delta\theta := 1 \cdot deg \qquad N\theta := \frac{90 \cdot deg}{\Delta\theta} + 1 \qquad \theta i := 1 .. N\theta \qquad \theta_{\theta i} := (\theta i - 1) \cdot \Delta\theta$$

elevation cut points

$$\Delta\phi := 3 \cdot deg \qquad N\phi := \frac{360 \cdot deg}{\Delta\phi} \qquad \phi i := 1 .. N\phi \qquad \phi_{\phi i} := (\phi i - 1) \cdot \Delta\phi$$

azimuth cut points

$$MBG := AG(\theta_o, \phi_o)$$

main beam gain

null-to-null beamwidth

```
BW(cut, Δψ) := | pt ← max(cut)
               | for i ∈ 1..rows(cut)
               |   indx ← i  if  cut_i = pt
               | i1 ← indx
               | while cut_(i1+1) ≤ cut_i1 ∨ cut_(i1+2) ≤ cut_i1 ∨ cut_(i1+3) ≤ cut_i1
               |   i1 ← i1 + 1
               | i2 ← indx
               | while cut_(i2−1) ≤ cut_i2 ∨ cut_(i2−2) ≤ cut_i2 ∨ cut_(i2−3) ≤ cut_i2
               |   i2 ← i2 − 1
               | (i1 − i2)·Δψ
```

$$HPBW(cut, \Delta\psi) := \left| \begin{array}{l} pt \leftarrow \max(cut) \\ \text{for } i \in 1..rows(cut) \\ \quad indx \leftarrow i \ \text{ if } cut_i = pt \\ i1 \leftarrow indx \\ \text{while } cut_{i1+1} > pt - 3 \\ \quad i1 \leftarrow i1 + 1 \\ i2 \leftarrow indx \\ \text{while } cut_{i2-1} > pt - 3 \\ \quad i2 \leftarrow i2 - 1 \\ (i1 - i2 + 1)\cdot\Delta\psi \end{array} \right.$$

HPBW

$\phi cut_{\phi i} := AG(\theta_o, \phi_{\phi i}) - MBG \quad BW_\phi := BW(\phi cut, \Delta\phi) \quad BW_\phi = 36\,deg$ normalized phi cut & beamwidth

$\theta cut_{\theta i} := AG(\theta_{\theta i}, \phi_o) - MBG \quad BW_\theta := BW(\theta cut, \Delta\theta) \quad BW_\theta = 20\,deg$ normalized theta cut & beamwidth

$HPBW_\theta := HPBW(\theta cut, \Delta\theta) \quad HPBW_\phi := HPBW(\phi cut, \Delta\phi)$ HPBWS

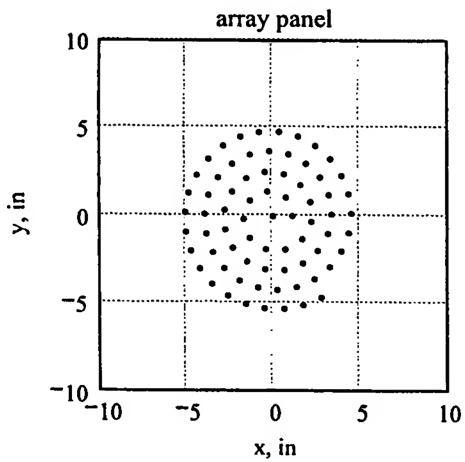
$Hemi_{\phi i, \theta i} := AG(\theta_{\theta i}, \phi_{\phi i}) - MBG \quad Hemi_{\phi i, \theta i} := if(Hemi_{\phi i, \theta i} < SLLgoal - 0.5, SLLgoal - 0.5, Hemi_{\phi i, \theta i})$ ıll hemispherical pattern normalized & clipped

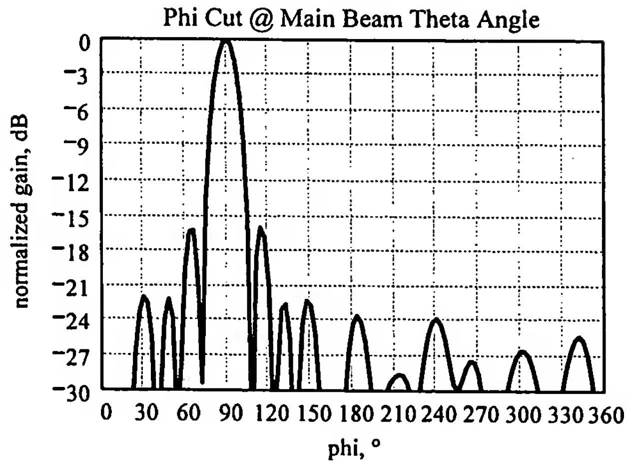
$$SLLcompliance := \left| \begin{array}{l} cnt \leftarrow 0 \\ \text{for } i \in 1..N\theta \\ \quad \text{for } k \in 1..N\phi \\ \quad\quad cnt \leftarrow cnt + 1 \ \text{ if } (Hemi_{k,i} \le SLLgoal) \vee (|\phi_o - \phi_k| \le BW_\phi \wedge |\theta_o - \theta_k| \le BW_\theta) \\ \dfrac{cnt}{N\phi \cdot N\theta} \end{array} \right.$$

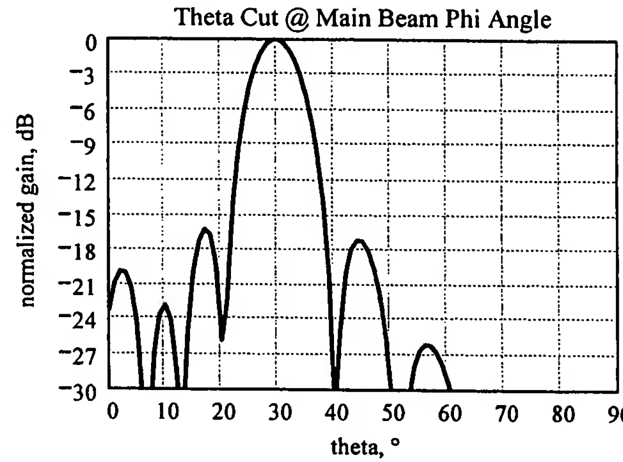
LL compliance

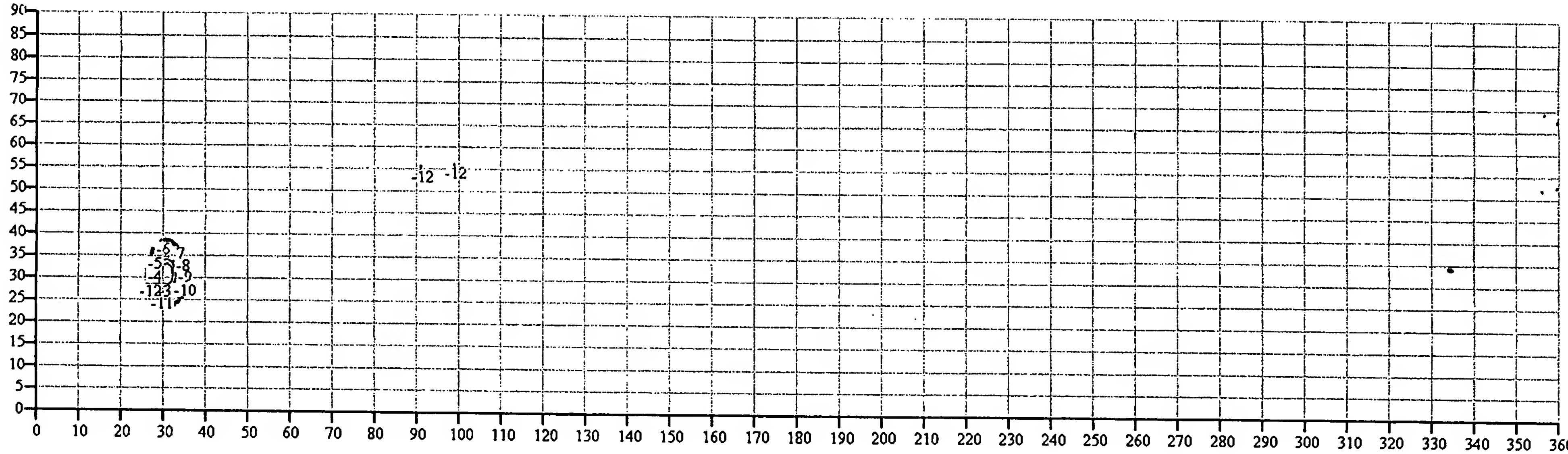
DESIGN

ElementGain(0·deg) = 8	$f \equiv 8.4 \cdot GHz$	element pattern file & frequency	$G_{array} = 26.6$	maximum possible array gain (dBiC)
SLLgoal ≡ −12.5		peak sidelobe compliance level	SLLcompliance = 99.9 %	SLL compliance
$\theta_o \equiv 30 \cdot deg$	$\phi_o \equiv 90 \cdot deg$	selected beam steering angles	MBG = 25.2	scanned main beam gain (dBiC)
nbits ≡ 4		# of phase shifter bits	$HPBW_\phi = 15\,deg$ $HPBW_\theta = 8\,deg$	HPBWs
MagErr ≡ 1.7	PhaseErr ≡ 30·deg	random magnitude error (dB) & random phase errors	$\eta = 63.24\%$ D = 1 ft D = 12 in	array efficiency & diameter
N ≡ 72		# of elements (1,8,21,40,64)	s = 1.123 in	required min spacing





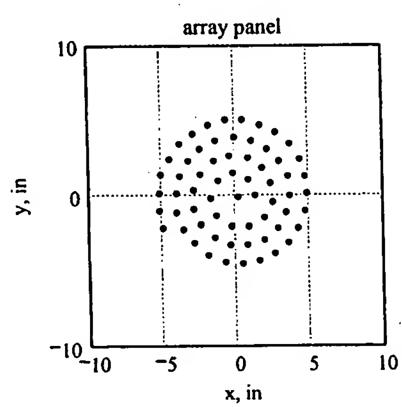


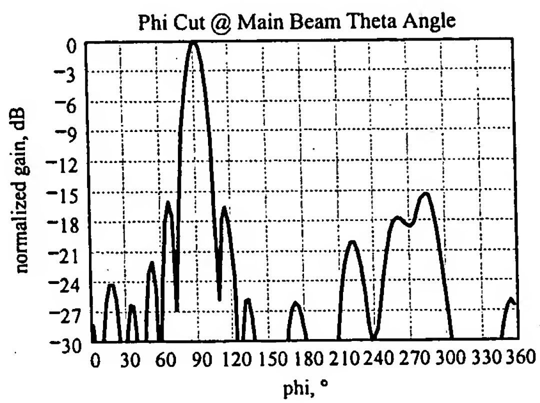


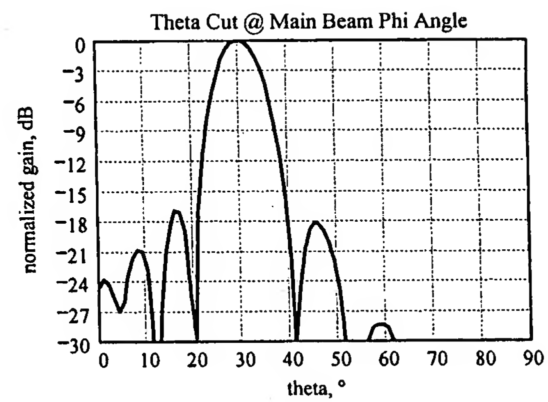
Hemi

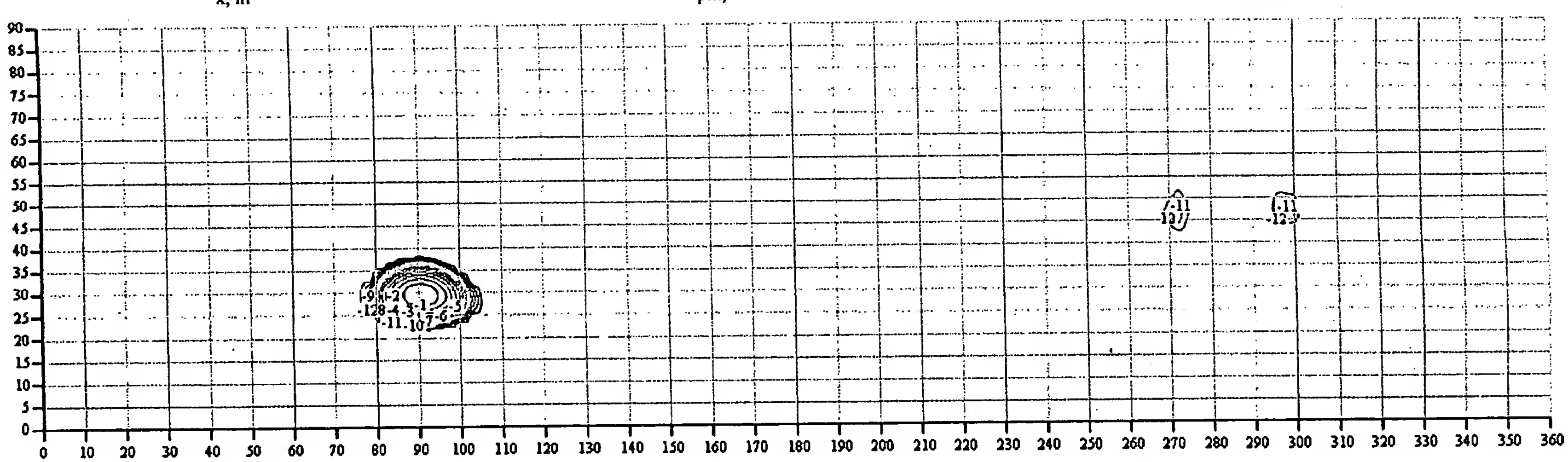
Not on chart

ElementGain(0deg) ≡ 8.5	f ≡ 8.4·GHz	element gain & frequency	G_{array} = 26.6	maximum possible array gain (dBiC)
SLLgoal ≡ −12.5		peak sidelobe compliance level	SLLcompliance = 99.7%	SLL compliance
θ_o ≡ 30·deg	ϕ_o ≡ 90·deg	selected beam steering angles	MBG = 24.9	scanned main beam gain (dBiC)
nbits ≡ 4		# of phase shifter bits		
MagErr ≡ 1.7	PhaseErr ≡ 30·deg	random magnitude error (dB) & random phase errors	$HPBW_\phi$ = 15deg $HPBW_\theta$ = 9deg	HPBWs
N ≡ 64		# of elements (1,8,21,40,64)	η = 62.398% D = 1 ft D = 12.1in	array efficiency & diameter
$\lambda \cdot D^{-1}$ = 6.68deg		boresight HPBW	s = 1.19in	required minimum element spacing





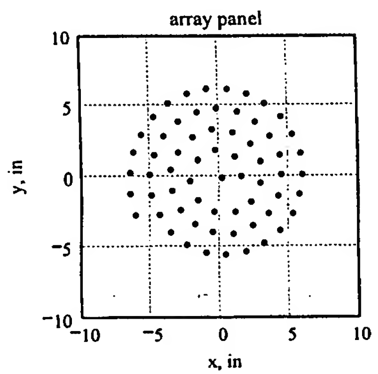


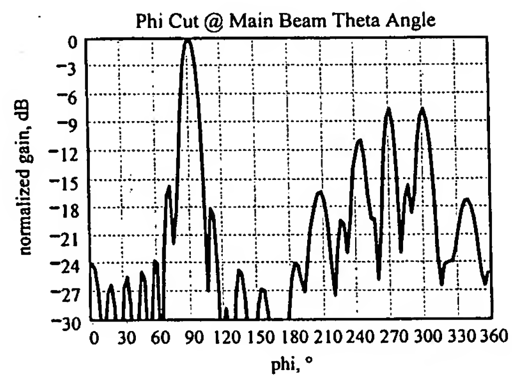


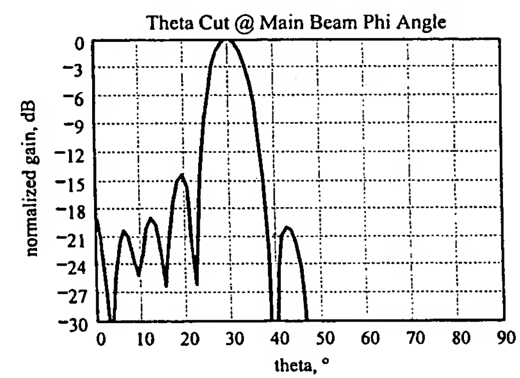
Hemi

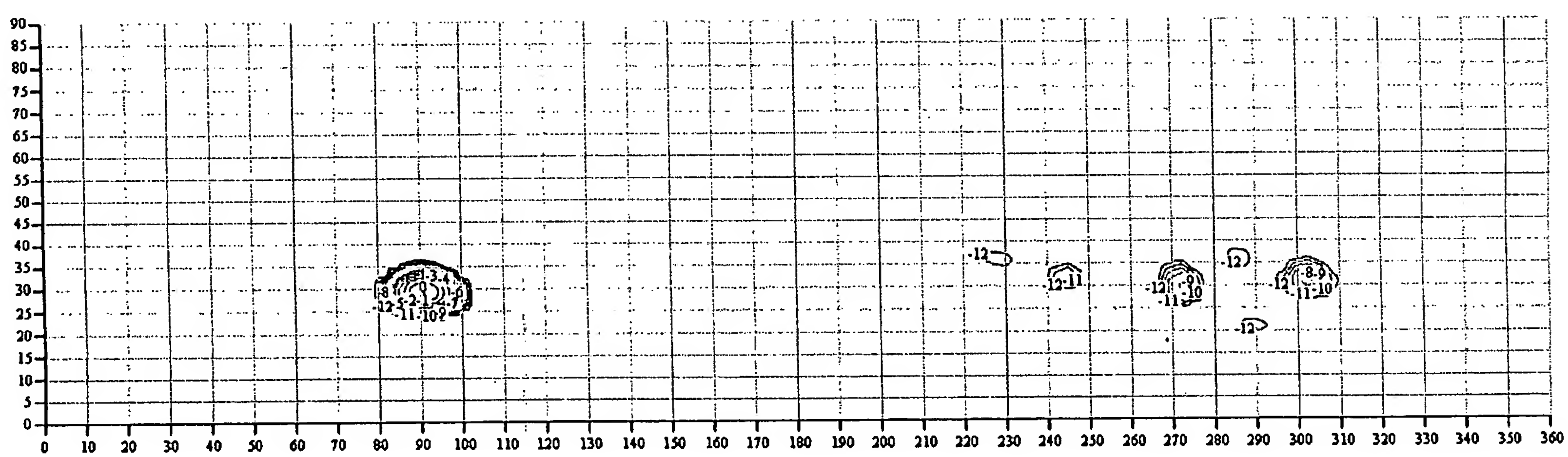
Not on chart

Element Gain(0deg) = 10.339	$f \equiv 8.4\,GHz$	element gain & frequency	$G_{array} = 28.4$	maximum possible array gain (dBiC)
$SLLgoal \equiv -12.5$		peak sidelobe compliance level	SLLcompliance = 98.919%	SLL compliance
$\theta_o \equiv 30\,deg$	$\phi_o \equiv 90\,deg$	selected beam steering angles	$MBG = 25.6$	scanned main beam gain (dBiC)
$nbits \equiv 4$		# of phase shifter bits		
$MagErr \equiv 1.7$	$PhaseErr \equiv 30\,deg$	random magnitude error (dB) & random phase errors	$HPBW_\phi = 12deg$ $HPBW_\theta = 8deg$	HPBWs
$N \equiv 64$		# of elements (1,8,21,40,64)	$\eta = 62.398\%$ $D = 1.2ft$ $D = 14.89in$	array efficiency & diameter
$\lambda \cdot D^{-1} \cdot 1.02 = 5.513deg$		boresight HPBW	$s = 1.471in$	required minimum element spacing







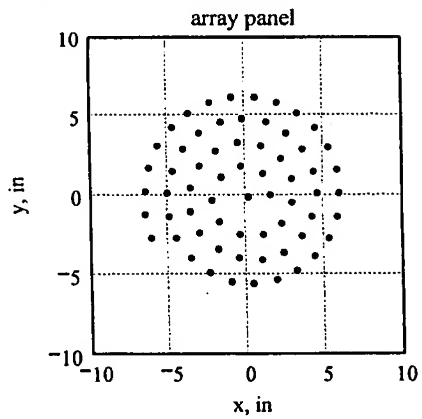


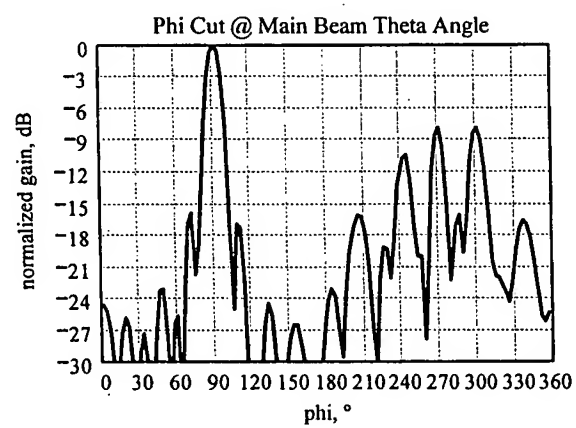
Hemi

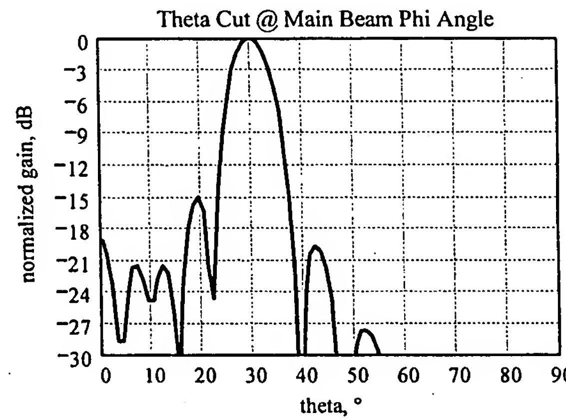
2

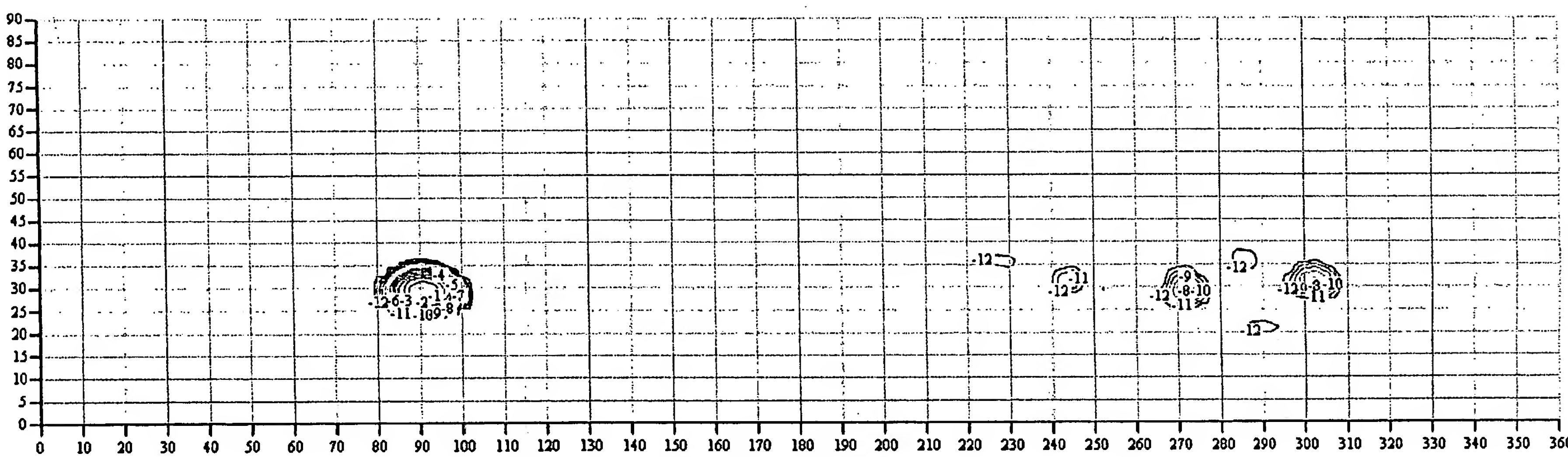
Row6 @ 8.4 GHz

ElementGain(0deg) = 10.334	$f \equiv 8.4\,GHz$	element gain & frequency	$\lambda \cdot D^{-1} \cdot 1.02 = 5.499\,deg$	boresight HPBW
lattice ≡ "archimed.txt"		lattice filename	$G_{array} = 28.4$	maximum possible array gain (dBiC)
$SLLgoal \equiv -12.5$		peak sidelobe compliance level	SLLcompliance = 98.9% PeakSLL = −7.7	SLL compliance & peak SLL (dB)
$\theta_o \equiv 30\,deg$	$\phi_o \equiv 90\,deg$	selected beam steering angles	$MBG = 25.6$	scanned main beam gain (dBiC)
$nbits \equiv 4$		# of phase shifter bits	$HPBW_\phi = 12\,deg$ $HPBW_\theta = 7\,deg$	main beam HPBWs
$MagErr \equiv 1.7$	$PhaseErr \equiv 30\,deg$	uniform random magnitude (dB) & phase errors	$\eta = 62\%$ $D = 1.2\,ft$ $D = 14.93\,in$	array efficiency & diameter
$N \equiv 64$		# of elements	$s = 1.47\,in$	required minimum element spacing







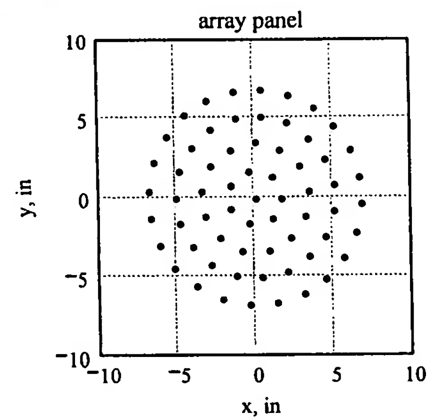


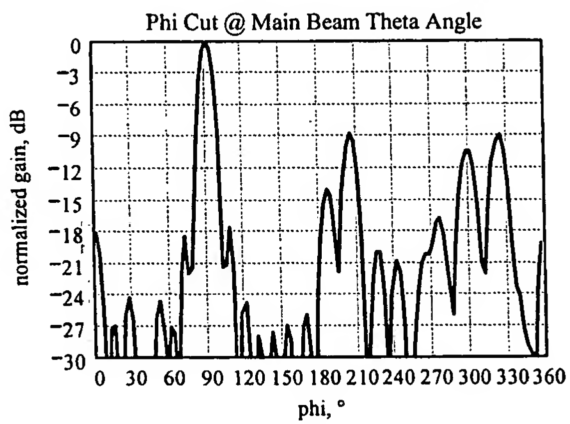
Hemi

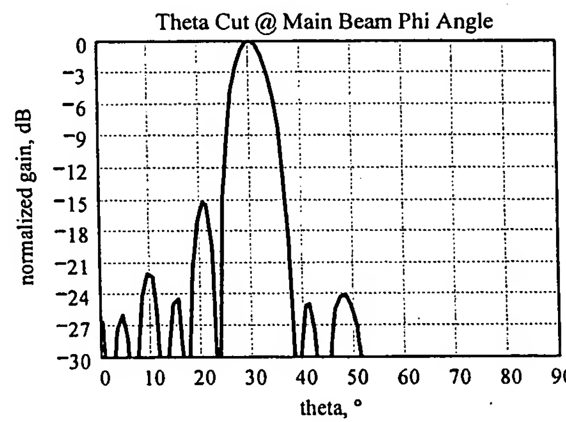
3

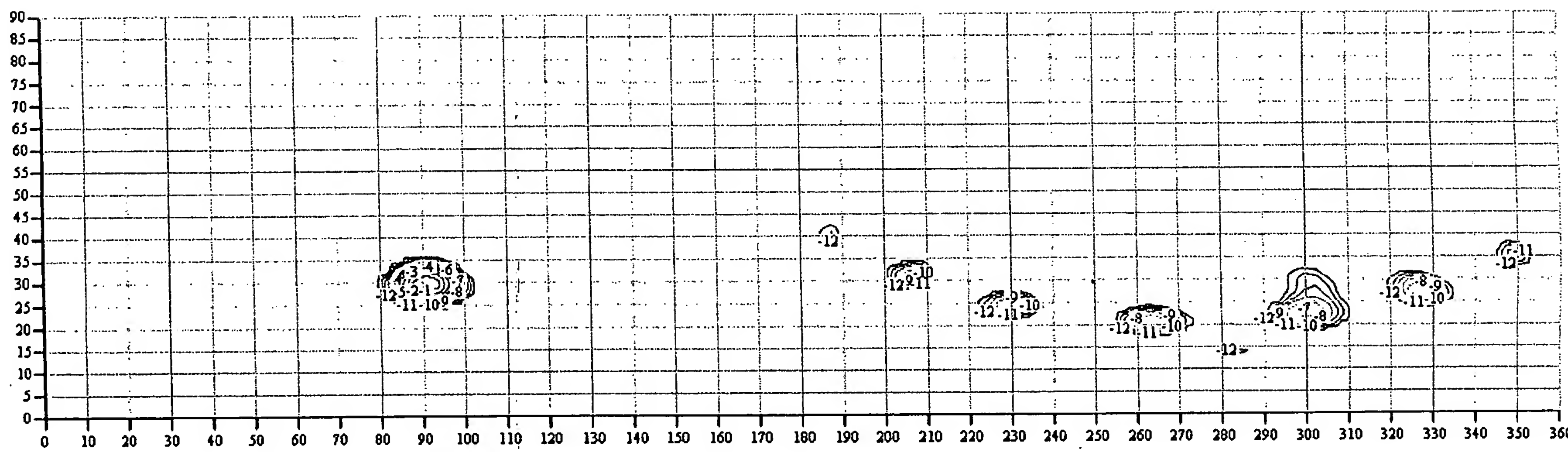
Row7 @ 8.4 GHz

ElementGain(0 deg) ≡ 10.334	f ≡ 8.4 GHz	element gain & frequency	$\lambda \cdot D^{-1} \cdot 1.02 = 5.427$deg	boresight HPBW
lattice ≡ "juniper.txt"		lattice filename	$G_{array} = 28.4$	maximum possible array gain (dBiC)
SLLgoal ≡ −12.5		peak sidelobe compliance level	SLLcompliance = 98% PeakSLL = −6.7	SLL compliance & peak SLL (dB)
$\theta_0 \equiv 30 \cdot$deg	$\phi_0 \equiv 90 \cdot$deg	selected beam steering angles	MBG = 25.6	scanned main beam gain (dBiC)
nbits ≡ 4		# of phase shifter bits	$HPBW_\phi = 9$deg $HPBW_\theta = 7$deg	main beam HPBWs
MagErr ≡ 1.7	PhaseErr ≡ 30·deg	uniform random magnitude (dB) & phase errors	$\eta = 60.4\%$ D = 1.3ft D = 15.13in	array efficiency & diameter
N = 64		# of elements	s = 1.47in	required minimum element spacing







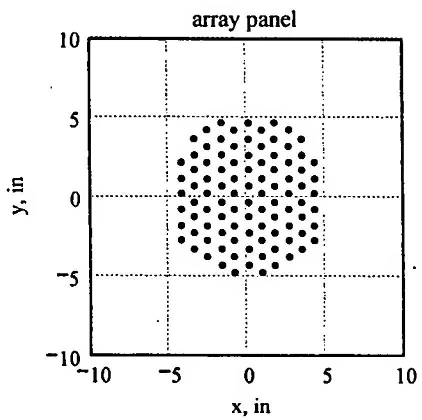


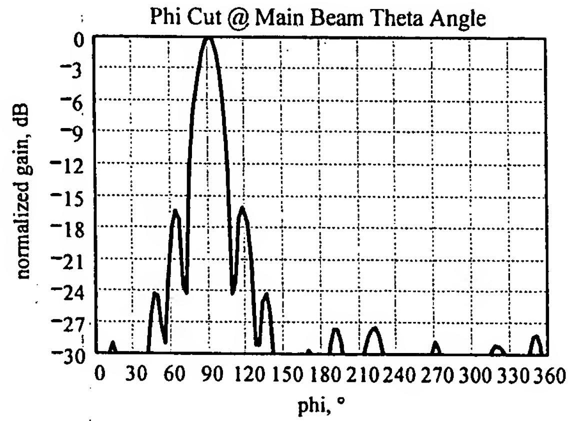
Hemi

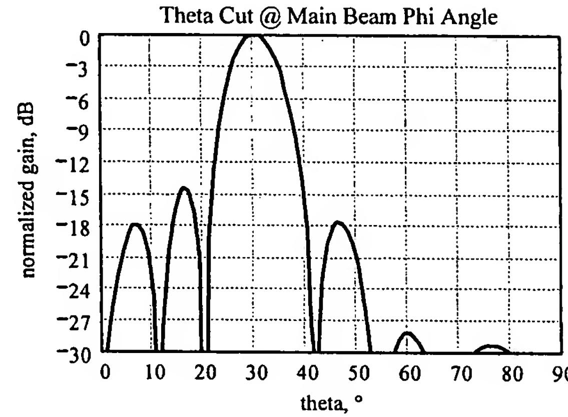
4

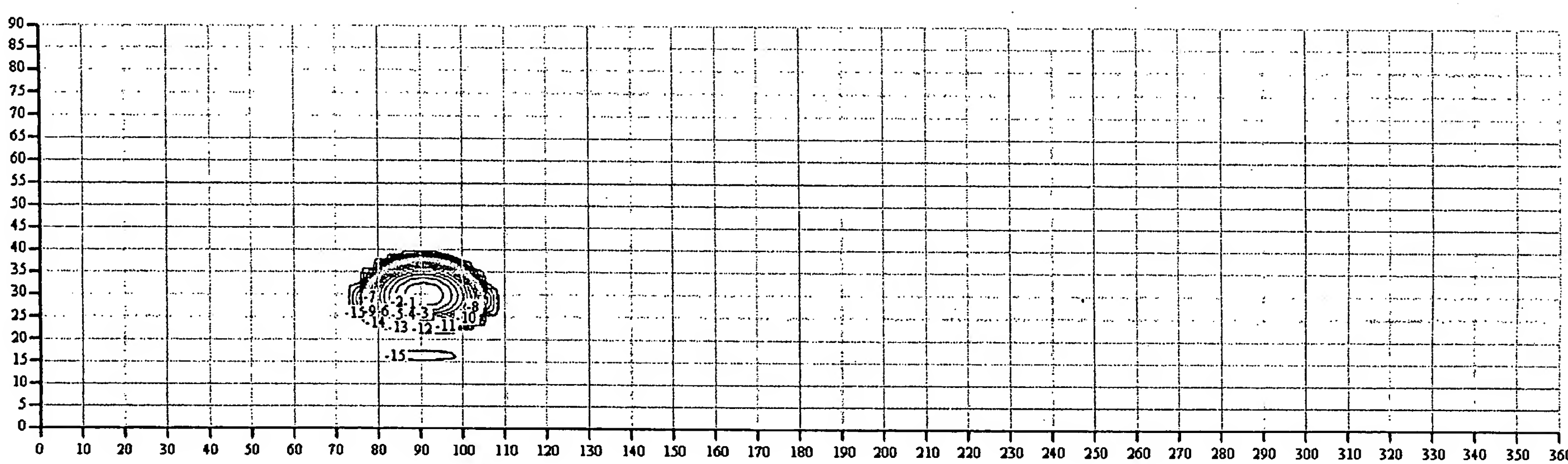
Row2 @ 8.4 GHz

ElementGain(0deg) = 6.902	$f \equiv 8.4\,GHz$	element gain & frequency	$\lambda \cdot D^{-1} \cdot 1.02 = 7.4\,deg$	boresight HPBW
lattice ≡ "tri96.txt"		lattice filename	$G_{array} = 26.7$	maximum possible array gain (dBiC)
$SLLgoal \equiv -12.5$		peak sidelobe compliance level	SLLcompliance = 100% PeakSLL = −15.5	SLL compliance & peak SLL (dB).
$\theta_o \equiv 30\,deg$	$\phi_o \equiv 90\,deg$	selected beam steering angles	MBG = 25.75	scanned main beam gain (dBiC)
$nbits \equiv 4$		# of phase shifter bits	$HPBW_\phi = 15\,deg$ $HPBW_\theta = 9\,deg$	main beam HPBWs
$MagErr \equiv 1.7$	$PhaseErr \equiv 30\,deg$	uniform random magnitude (dB) & phase errors	$\eta = 75.4\%$ $D = 0.9\,ft$ $D = 11.169\,in$	array efficiency & diameter
N ≡ 96		# of elements	$s = 0.99\,in$	required minimum element spacing







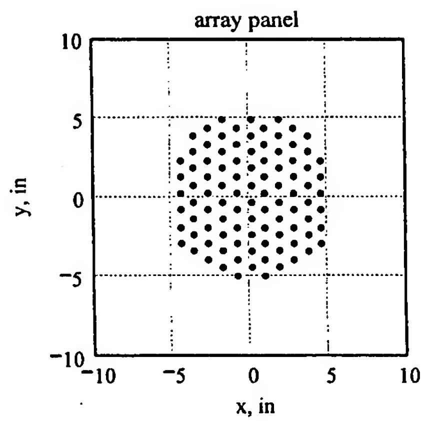


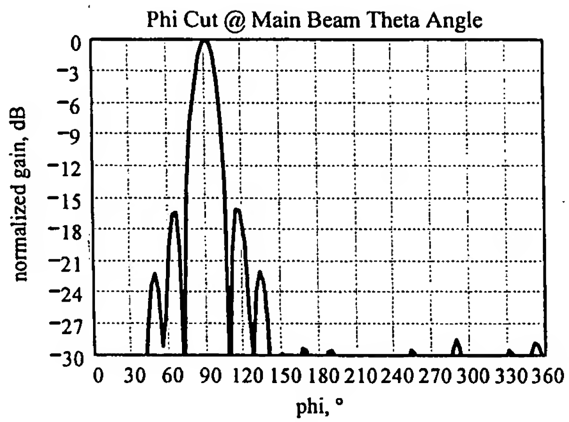
Hemi

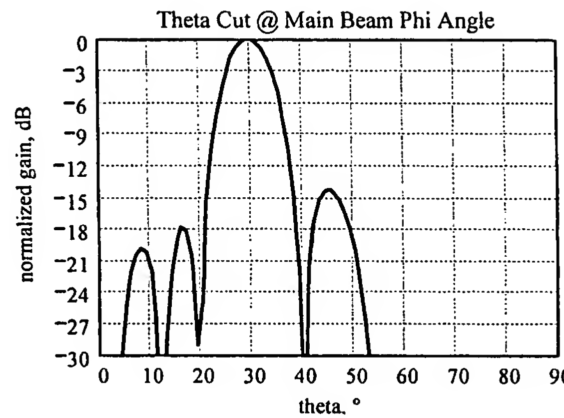
5

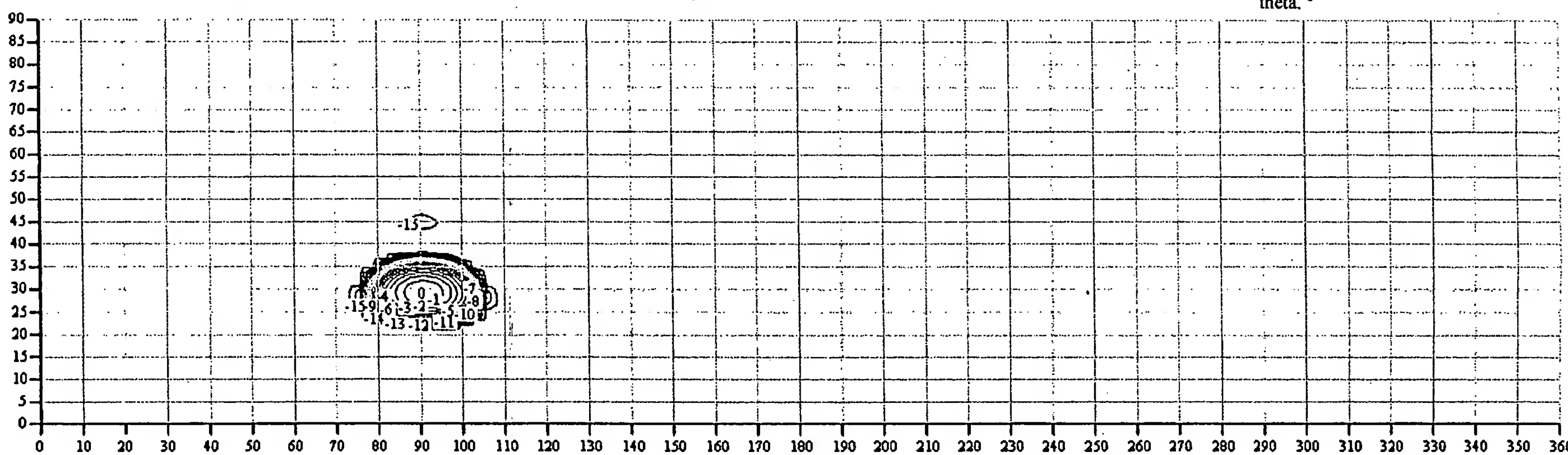
NOT ON CHART

Element Gain(0 deg) = 7.3	$f \equiv 8.4\,GHz$	element gain & frequency	$\lambda \cdot D^{-1} \cdot 1.02 = 7\,deg$	boresight HPBW
lattice ≡ "tri96.txt"		lattice filename	$G_{array} = 27.1$	maximum possible array gain (dBiC)
$SLLgoal \equiv -12.5$		peak sidelobe compliance level	SLL compliance = 100% Peak SLL = -14.5	SLL compliance & peak SLL (dB)
$\theta_o \equiv 30\,deg$	$\phi_o \equiv 90\,deg$	selected beam steering angles	$MBG = 26$	scanned main beam gain (dBiC)
$nbits \equiv 4$		# of phase shifter bits	$HPBW_\phi = 15\,deg$ $HPBW_\theta = 8\,deg$	main beam HPBWs
$MagErr \equiv 1.7$	$PhaseErr \equiv 30\,deg$	uniform random magnitude (dB) & phase errors	$\eta = 75.4\%$ $D = 1\,ft$ $D = 11.7in$	array efficiency & diameter
$N = 96$		# of elements	$s = 1.039in$	required minimum element spacing







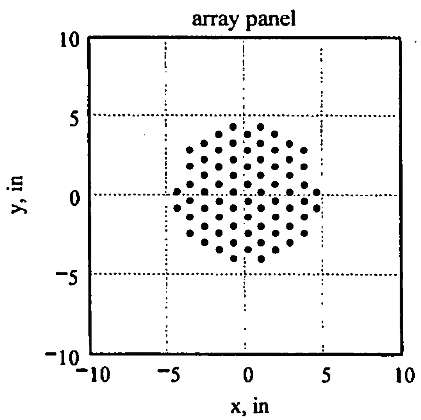


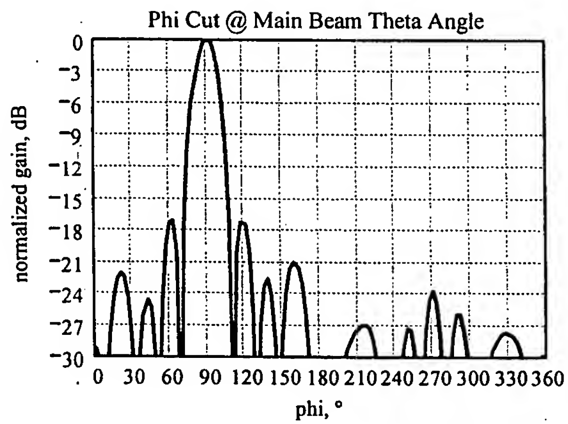
Hemi

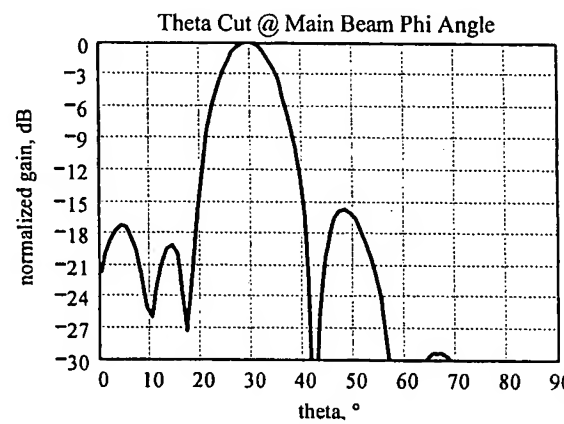
6

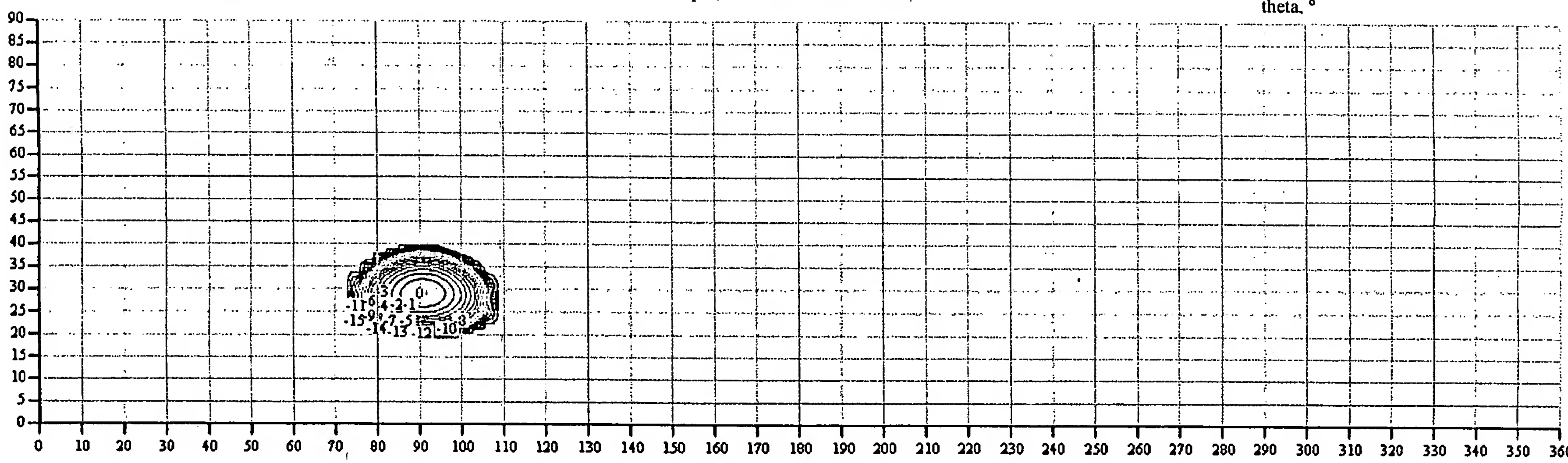
Row5 @ 8.4 GHz

ElementGain(0deg) ≡ 7.324	$f \equiv 8.4\,\text{GHz}$	element gain & frequency	$\lambda \cdot D^{-1} \cdot 1.02 = 8.011\,\text{deg}$	boresight HPBW
lattice ≡ "lat72.txt"		lattice filename	$G_{array} = 25.897$	maximum possible array gain (dBiC)
SLLgoal ≡ −12.5		peak sidelobe compliance level	SLLcompliance = 99.9% PeakSLL = −15.5	SLL compliance & peak SLL (dB)
$\theta_o \equiv 30\,\text{deg}$	$\phi_o \equiv 90\,\text{deg}$	selected beam steering angles	MBG = 24.733	scanned main beam gain (dBiC)
nbits ≡ 4		# of phase shifter bits	$HPBW_\phi = 15\,\text{deg}$ $HPBW_\theta = 11\,\text{deg}$	main beam HPBWs
MagErr ≡ 1.7	PhaseErr ≡ 30deg	uniform random magnitude (dB) & phase errors	$\eta = 74.02\%$ D = 0.9ft D = 10.251in	array efficiency & diameter
N ≡ 72		# of elements	s = 1.039in s = 0.74λ	required minimum element spacing







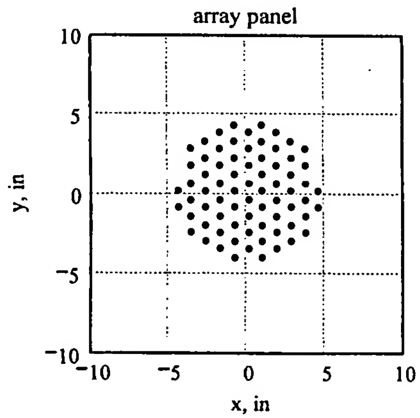


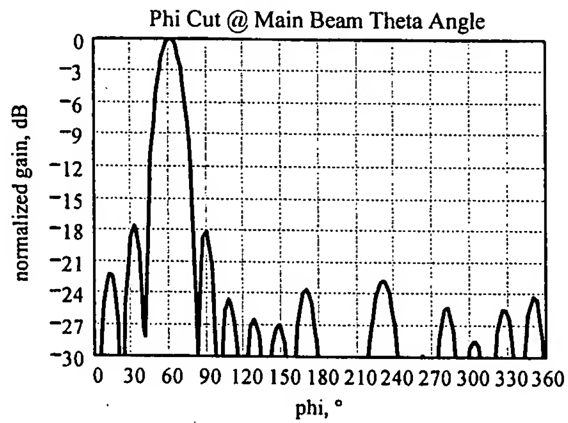
Hemi

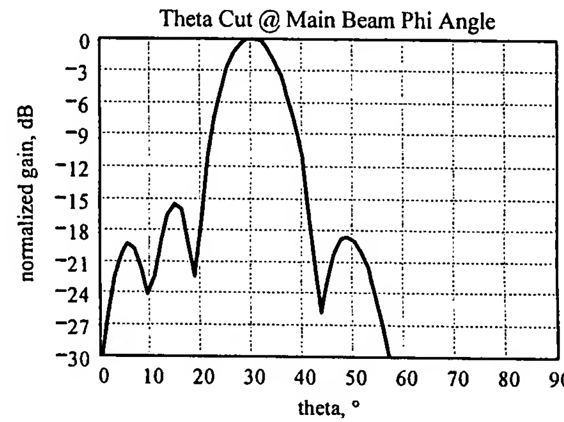
7

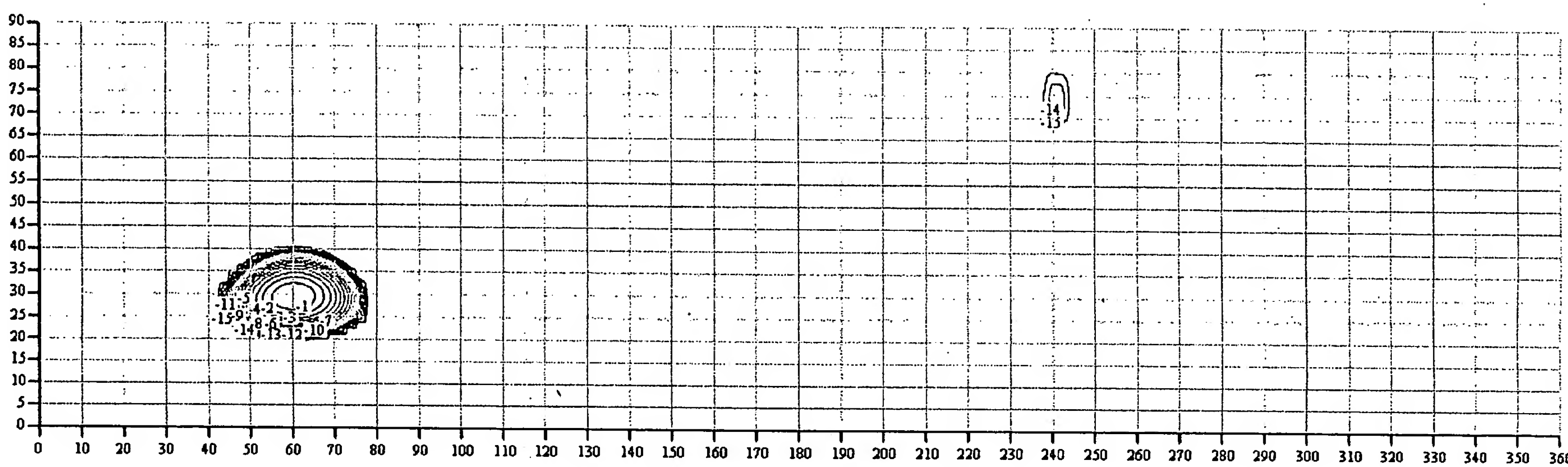
72 element triangular lattice scaled 1.05 - scanned to phi=60° (worst case not phi=90°)

ElementGain(0deg) = 7.324 $f \equiv 8.4\,GHz$	element gain & frequency	$\lambda \cdot D^{-1} \cdot 1.02 = 8.011deg$	theoretical boresight HPBW
lattice ≡ "lat72.txt"	lattice filename	$G_{array} = 25.897$	maximum possible array gain (dBiC)
$SLLgoal \equiv -12.5$	peak sidelobe compliance level	SLLcompliance = 100% PeakSLL = −13.4	SLL compliance & peak SLL (dB)
$\theta_0 \equiv 30 \cdot deg$ $\phi_0 \equiv 60 \cdot deg$	selected beam steering angles	$MBG = 24.768$	scanned main beam gain (dBiC)
$nbits \equiv 4$	# of phase shifter bits	$HPBW_\phi = 17.7deg$ $HPBW_\theta = 10.5deg$	main beam HPBWs
$MagErr \equiv 1.7$ $PhaseErr \equiv 30 \cdot deg$	uniform random magnitude (dB) & phase errors	$\eta = 74.02\%$ $D = 0.9ft$ D = 10.251in	array efficiency & diameter
$N \equiv 72$	# of elements	$s = 1.039in$ $s = 0.74\lambda$	required minimum element spacing





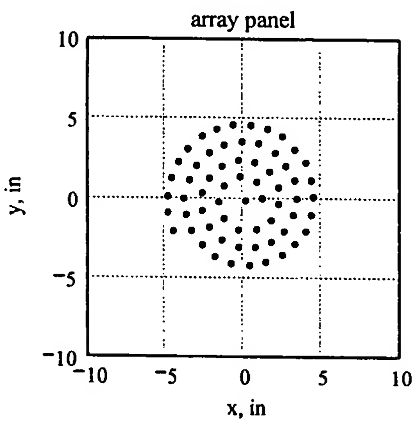


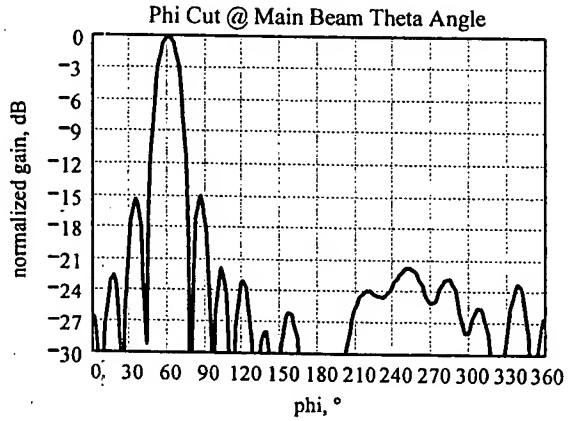


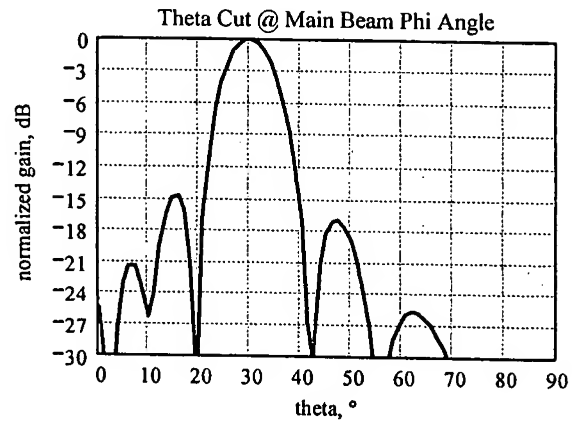
Hemi

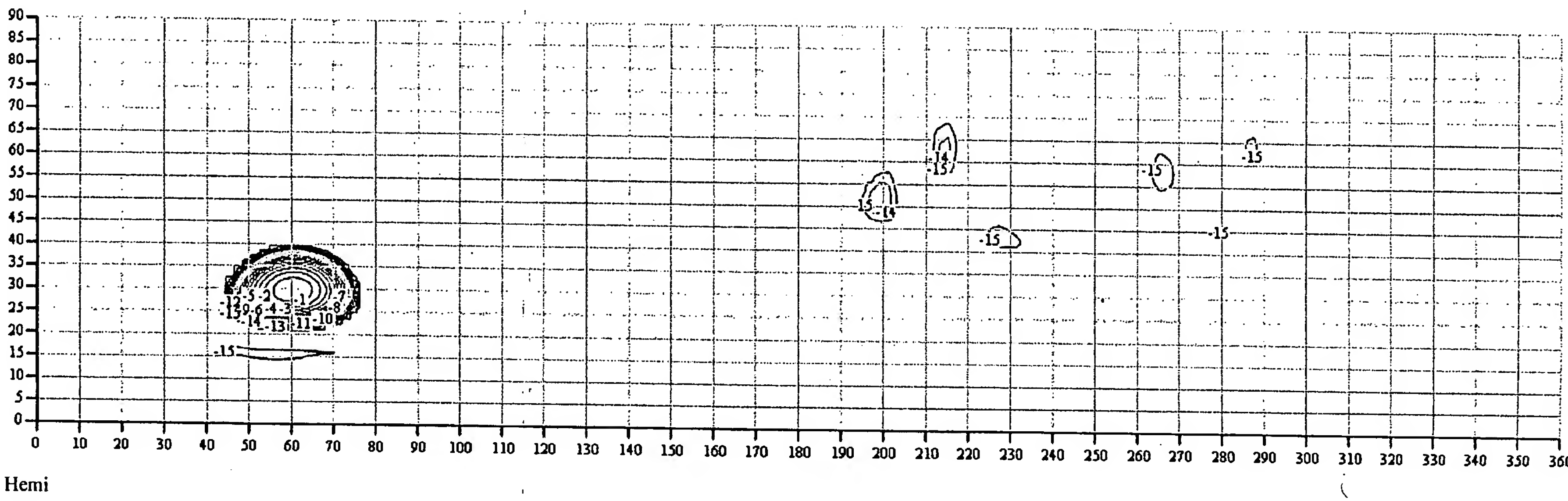
64 element archimedes spiral lattice with 7.78 dB elements - scanned to phi=60° (worst case?)

ElementGain(0deg) = 7.78 f ≡ 8.4 GHz	element gain & frequency	$\lambda \cdot D^{-1} \cdot 1.02 = 7.378\text{deg}$	theoretical boresight HPBW
lattice ≡ "regspiral.txt"	lattice filename	$G_{array} = 25.843$	maximum possible array gain (dBiC)
SLLgoal ≡ −12.5	peak sidelobe compliance level	SLLcompliance = 100% PeakSLL = −13.91	SLL compliance & peak SLL (dB)
$\theta_o \equiv 30\text{deg}$ $\phi_o \equiv 60\text{deg}$	selected beam steering angles	MBG = 24.536	scanned main beam gain (dBiC)
nbits ≡ 4	# of phase shifter bits	$HPBW_\phi = 16\text{deg}$ $HPBW_\theta = 9.7\text{deg}$	main beam HPBWs
MagErr ≡ 1.7 PhaseErr ≡ 30 deg	uniform random magnitude (dB) & phase errors	$\eta = 62.013\%$ D = 0.9ft D = 11.13in	array efficiency & diameter
N = 64	# of elements	s = 1.096in $s = 0.78\lambda$	required minimum element spacing









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